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A. TITLE:

$\gamma d \to pn$ Reaction Asymmetry Cross-Section Measurements

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RESEARCH PROPOSAL FOR CEBAF PAC5
$\gamma d \rightarrow pn$ REACTION ASYMMETRY CROSS-SECTION MEASUREMENTS

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RESEARCH PROPOSAL CEBAF

$\gamma d \to pn$ REACTION ASYMMETRY CROSS-SECTION MEASUREMENTS

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ABSTRACT

We propose to measure the asymmetry of the $d(\gamma,p)n$ reaction in the photon energy range E_γ=0.6-2.0 GeV. These measurements allow one to study the validity of existing nuclear-physics models in high energy region, the non-nucleonic degrees of freedom and multi-quark configurations in the deuteron and the deuteron wave function at small distances. Experimental results will give the possibility to check the existence of the asymptotic scaling phenomenon in the deuteron photodisintegration reaction at high energies.

The experiment will become a constituent of the complex studies of the $d(\gamma,p)n$ reaction that has been suggested at CEBAF [1].

INTRODUCTION

During more than 50 years special attention has been paid to deuteron photodisintegration reaction

$$\gamma d \rightarrow pn , \qquad (1)$$

because it is a simplest nuclear process, the studies of which all[illegible] one to examine the fundamental ideas of nuclear and element[illegible] particles of physics at all stages of their development.

At present the energies exceeding 0.5 GeV are thought to be m[illegible] interesting for studies. Reaction mechanisms here are complicated [illegible] change essentially on increasing energy. In the range $E_\gamma \leq$ 1 GeV [illegible] may probably succeed to describe this process in the frame of [illegible] nucleon-meson theory. However up to now there is not solved [illegible] problem of wave function behavior at small ($\leq$0.5 Fermi) distances, [illegible] well as questions about the deuteron non-nucleonic degrees of freed[illegible] In the range $E_\gamma \geq$ 1.4 GeV, as it follows from the recent measuremen[illegible] at SLAC [2], reaction mechanisms due to inner structure of [illegible] deuteron nucleons are possible.

One should expect that the qualitatively new information ab[illegible] the process (1) in the energy range given (E_γ >0.5 GeV) may [illegible] obtained as a result of studying polarization observables that a[illegible] often more sensitive to reaction mechanism details and to theoretic[illegible] models than the cross-sections. Specifically, it seems to be importa[illegible] to study the asymmetry of cross-sections

$$\Sigma=(d\sigma_{\parallel}-d\sigma_{\perp})/(d\sigma_{\parallel}+d\sigma_{\perp}), \qquad (2)$$

where $d\sigma_{\parallel(\perp)}=d\sigma_{\parallel(\perp)}/d\Omega$ is the reaction cross-section when the phot[illegible] polarization vector is directed parallel (perpendicular) to t[illegible] reaction plane. This experiment is interesting and relatively simp[illegible] therefore it may start at the initial stage of mastering t[illegible] accelerator and the experimental techniques, because:

a) it doesn't require large electron currents an therefore, deuteron targets with large cooling power;

b) it doesn't require complicated detecting system for detecti of reaction products;

c) only relative measurements are required, absolute measuremen are not;

d) there are no problems connected with proton spin rotation in spectrometer magnetic field, as well as with the polarizati analyzer.

MOTIVATION

CEBAF proposals [1] cover in sufficient measure the status of t theoretical description of deuteron photodisintegration reaction (and the foundation of the necessity of its experimental studies. support of all these arguments we note only the following:

1. Experimental studies of the energy range 0.6-2 GeV are f from complete yet. The bulk of experimental data base now at hand concentrated in the range of comparatively moderate energies E 0.7-0.8 GeV. There are no polarization data in the range E_γ >1 GeV.

2. Reaction (1) has been intensively studied during last 10 yea at Kharkov Institute of Physics and Technology (KhIPT). There ha been measured the differential cross-sections $d\sigma/d\Omega$, with t non-polarized bremsstrahlung photon beam, the cross-sections $d\sigma_\parallel/$ and $d\sigma_\perp/d\Omega$ with polarized photons in the range 0.04-0.1 GeV [3], t asymmetry of cross-sections Σ in the energy range 0.04-0.6 G [3,4], the proton polarization P in the range 0.4-1 GeV [5]. There al have been performed measurements of the observable T_1 (polarizati asymmetry) in the double polarization experiment (polariz beam-proton polarization) in the energy range 0.4-0.6 GeV [6].

3. Theoretical studies in the 0.6-2 GeV range are scarce and,

general, no model describes all experimental data in the energy ran discussed. Thus, calculations [7,8] may more or less satisfactori describe only differential cross-sections for angles θ_p^{cm} 90^o. Experimental data on cross-sections at small ($\theta_p^{cm} \leq 30^o$) and lar ($\theta_p^{cm} \geq 140^o$) angles, as well as the data on polarization observables and Σ are described unsatisfactorily, Fig.1. The analysis of the theoretical works, as well as of calculations [8-10], in which f improvement of the agreement between theory and experiment assumption about the dibaryon resonances is made , has shown th calculations of one or two observables (cross sections, nucle polarization) and their satisfactory agreement with the existing da are not, generally speaking, a proof that mechanisms of the reactic are correctly understood and model parameter values are correct. It so because to describe the reaction (1) it is necessary, in principl to construct a large number of independent amplitudes (12) containi also a large number of parameters that are unknown now. T measurements of a new observable lead, as a rule, to the necessity reconsidering the theoretical representations, especially f calculations at energies higher than 0.3 GeV.

In such a situation it is especially important, in our opinic not to increase the accuracy of measuring one or another observabl but rather to increase a number of new independent observabl measured.

Similar experiments at energies $E_\gamma \leq 1$ GeV are being planned ELSE, MEA accelerators and others. In this connection it see principally important to add to the CEBAF investigation program studying the reaction (1) the measurements of cross-section asymmet with linear polarized photons at energies up to 2-3 GeV whe according to data of paper [2] a phenomenon of asymptotic scaling [may be observed already at $E_\gamma \geq 1.4$ GeV.

The theoretical calculations of polarization observables for th energy range are not published, regrettably. The conventior approaches in the asymptotic limit lead, probably, to zero effects f

some polarization observables ,for example P, T. As to cross sec
asymmetry, its value, if assumption about asymptotic scaling [11]
true ,may be, in principle equal ~ 1 (or -1, depending on rela
sign phase of amplitude deuteron photodisintegration). The exis
experimental data on proton polarization [5] and asymmetry [4,
covering the energy range up to 1 GeV show that the pr
polarization (0.7-0.8) is sufficiently large but the asymmetry
small (~0.2) and tends to diminish on increasing energy. However th
data need checking. The calculations performed recently in Khar
[13] point to the specific sensitivity of the cross-section asymme
to the Roper configuration in the deuteron wave function. Its acc
influences very strongly the asymmetry value at $E_\gamma \approx 1-1.2$
decreasing it from 0.7 to 0.2.

On the whole, the experimental check of similar qualitat
conclusions about the behavior of polarization observables in the h
energy range is of special interest and may be effective test of
assumption about asymptotic scaling [11].

GENERAL DESCRIPTION OF THE EXPERIMENT

It is proposed to measure the cross-section asymmetry of
$d(\gamma,p)n$ reaction in the photon energy range E_γ=0.6-2.0 GeV for
angles θ_p^{cm} = 30°, 60°, 90°, 120°, 150°.

The measurements in the vicinity of the lower boundary of
energy range are performed for comparison with existing data.
measurements in the region of 2 GeV may be possible to perform in
near future only at CEBAF.

The experiment is to be performed with the linearly polari
photons obtained from electron coherent bremsstrahlung in diam
single crystal. The separation of the reaction studied from
background of competing processes is accomplished by requiring
coincidences.

EXPERIMENTAL TECHNIQUE AND PROCEDURE

The parameters of the CEBAF accelerator designed are advantage for the successful performing of the experiment: high duty fact high current and initial energy of electrons and small dimensions the beam spot.

The suggested scheme of the experiment is shown in Fig. 2. electron beam is brought into the diamond monocrystal fixed goniometric set. The deuterium target is located at the sm distance~ 0.8-1 m from the photon target. Since the deuteron target this experimental scheme is irradiated with photons and electro measurements are necessary to subtract the contribution due electrodisintegration processes. Measurements may also be necess with the empty deuteron target to determine the contribution from target walls.

In the experiment it is suggested to use a liquid deuter target 10 cm long (t_D=0.0142X_0) capable of the electron currents to 60 μA.

Calculations of expected yields of pn coincidences from deute photo- and electrodisintegration reactions have shown, that the pho target thickness should amount to not less than ~ 0.05 - 0.06X_0 achieve the desired < 50% value of the electrodisintegrat contribution to the full yield ratio. If one uses a diam monocrystal as a photon target (X_0= 12.8 cm), which is most frequen used to obtain the polarized photons because of the high De temperature, its thickness may be ~ 6 mm.

If the monocrystal target is oriented with respect to t electron beam in such a way that the main contribution to the coher bremsstrahlung cross-section was made by one point of the inver lattice $(2,\bar{2},0)$ then the expected photon spectra and the radiat polarization for some energy values of the coherent bremsstrahl peak are shown in Fig. 3 at the initial energy of electrons E_0= 4 Ge The $(2,\bar{2},0)$ orientation is most often used in experiments because allows one to obtain higher polarization than other possible orientations.

CRYSTAL ORIENTATION AND POLARIZATION DETERMINATION

Crystal orientation is a procedure consisting of aligning the beam axis $\vec{P}_0$ with one of the main crystal axes, e.g. with $\vec{B}_1 = \langle 110 \rangle$ and with the other two axes $\vec{B}_2 = \langle 110 \rangle$ and $\vec{B}_3 = \langle 001 \rangle$ directed along the horizontal and vertical rotation axes of the goniometer. On realizing it one usually performs special measurements of orientation dependencies of the photon beam intensity with an ionization chamber, or a quantometer, or pair spectrometer. Because experimental halls "A" are not equipped with magnets to clean the photon beam from the electron contamination, this conventional technique cannot be applied.

In such situation, in our opinion, for the hall "A" conditions the most promising is a some modification of the conventional method. For its realization in the hall "A" CEBAF, it is necessary to deflect the electron beam, after its passage through the single crystal, by a small bending magnet so, that the beam on its way to the beam dump should pass by the ionization chamber, fig.4. Bending magnet is installed directly after the deuteron target. Ionization chamber measuring 20x20 mm is placed at hall "A" exit (about 20-25 m from deuteron target). There is a deflection the electron beam on angle of $\sim$ 5 mrad provide the displacement it on the distance of 100-120 mm at the region of the ionization chamber. The angle of the multiple scattering of the electron beam after its passage through the diamond single crystal and deuteron target consist of about 1 mrad for electron energy 4 GeV.

In order to deflect the electron beam with energy 4 GeV at angle about 5 mrad it is enough to have a magnet with field about 5 kilogauss and length of magnetic path $\sim$ 13 cm. In such case electrons of the beam with energies $E_0 \geq 1.05$ GeV will get in beam dump of the hall "A" ($E_o \approx 1.05$ GeV correspond point A on fig 4), which accordir to design have long about 30 m and diameter ~ 2 m, and the electror with energy $E_o \geq 0.5$ GeV will get in the tunnel of beam dump ($E_o \gtrsim$ 0. GeV correspond point B). So practically all electron beam shall get i tunnel of the beam dump Besides, expediently the orientation of th crystals may carry out on lower intensity of the beam ~ 0.01 μka. Th bending magnet my be switch off, when crystal orientation is finishec

The orientation dependencies of the collimated photon beam obtained with this arrangement on Kcharkov Linac (the deflecte electron beam passed at a distance of ~ 20 cm from ionizatic chamber), turned out to be practically the same as those for th traditional experimental set-up, fig.5.

It is suggested to determine the degree of photon polarization i the range of the coherent peak maximum from the measured orientatic dependencies of reaction (1) yield $C_{\parallel(\perp)}(\theta_p, P_p, \theta, \alpha)$ at fixed value of kinematic variables θ_p and P_p (proton angle and momentum) corresponding to the photon energy value chosen, when the polarizatio vector is parallel (perpendicular) to the reaction plane. θ is th angle between the electron momentum $\vec{P}_o$ and $\vec{B}_1$ axis, α is the angl between the planes ($\vec{P}_o$, $\vec{B}_1$) and ($\vec{B}_1$, $\vec{B}_2$). These angles are determine uniquely by the energy of the coherent peak in the bremsstrahlun spectrum. The effective polarization near the peak in the case whe the main contribution to the bremsstrahlung cross-section is made b one point of the crystal inverse lattice $(2,\bar{2},0)$ equals, according t [4]:

$$P_\gamma = k \frac{2(1-X)}{[1+(1-X)^2]} * \frac{\beta - 1}{\beta}, \quad (3)$$

where $X = E_\gamma / E_o$, $\beta = (C_\parallel^{max} + C_\perp^{max}) / 2C_a$;

$C_{\parallel\perp}^{max}$ - the proton yield in the maximum of the orientatio dependence $C_{\parallel,\perp}(\theta_p, P_p, \theta, \alpha)$,

C_a - the yield under the same kinematic conditions measured witl non-oriented crystal.

The coefficient K accounts for the small contribution into coherent bremsstrahlung cross-section from the other points of diamond inverse lattice and it changes from 0.98 to 0.9 on changing from 0.1 to 0.4.

THE $\gamma d \to pn$ REACTION IDENTIFICATION

In contrast to SLAC experiment [2] where measurements have b performed at the end of the photon bremsstrahlung spectrum, in experiment suggested it is necessary to measure the reaction yields due to photons from the coherent peak which must be at relat energy $X \leq 0.5$ to have the sufficiently high photon polarization.

Therefore the conditions for the reaction identification w differ essentially. To separate reaction (1) from the background it necessary to use the pn coincidence technique in this case. To det protons it is suggested to use the detector assembly for H spectrometer in hall "A".

For neutron registering one can use a hodoscope consisting of counters out of plastic scintillator 20 cm thick, 10 cm wide and 16 cm high (the overall size of the hodoscope is 30 cm horizontally 65 cm vertically) placed 5 m from the deuteron target center. geometric dimensions given allow one to couple the solid angles proton and neutron arms when registering pn coincidences at angle 9 In front of every neutron counter of the hodoscope the a coincidence scintillation counters with dimensions $10\times16.25\times1$ cm^3 placed to suppress the charged particle background.

The neutron telescope is located on the rotating platform ins a shield of concrete blocks. In front of it a lead absorber 10 thick ($17.68X_0$) is placed to lower the counter load with char particles and photons. For a more reliable separation of the deuter photodisintegration channel one can measure neutron energies us time-of- flight technique, together with the angles. Time resoluti of 0.3 nsec will give energy resolution not worse than 10% in energy range studied.

ESTIMATES OF PROTON AND NEUTRON COUNTING RATES

Counting rates of proton and neutron channels have been estima for the angles $\theta_p^{cm} = 30^\circ, 60^\circ, 90^\circ, 120^\circ, 150^\circ$ in the photon energy ra 0.6–2 GeV. The corresponding kinematic conditions are listed in Ta 1.

In calculations one has assumed that:

- the solid angle of the HRHS spectrometer for proton is 7 x 1 sr, the momentum acceptance $\Delta p/p = 0.05$;
- deuteron target is 10 cm thick (0.51×10^{24} nuclei per cm^2);
- inlet and outlet windows are 0.1 mm aluminum thick (1.20x1 nuclei per cm^2);
- neutron detection efficiency is 0.2;
- neutron transmission coefficient in the 10 cm lead filter 0.57;
- detection efficiency in proton arm is 100%;
- diamond monocrystal is 6 mm thick. Energy of the prim electron beam is 4 GeV.

To calculate the $d(\gamma,p)n$ reaction yield one has evaluated number of real photons for an oriented and disoriented diamond crys in the photon energy range determined by the reaction kinematics particle acceptance over momenta $\Delta p/p = 0.05$.

Data on the differential cross section of the $d(\gamma,p)n$ react for $\theta_p^{cm} = 90^\circ$ have been taken from the CEBAF proposal [1] and ones the 2 GeV energy have been obtained by their extrapolation. Tabl lists the cross section values. Data on the differential cr sections at angles $30^\circ, 60^\circ, 120^\circ$ and 150° have been taken the same for 90°.

For angle 30° the calculation also have been done differential cross section, which may be obtain from theoretic approach [13]. In this approach the cross section at θ_p^{cm} = 30^o prov to be about 2.3 times for E_γ = 1 GeV and about 7.5 times for E_γ = GeV greater then cross sections at θ_p^{cm} = 90^o. For other phot energies cross sections have been obtained by interpolation. T results are listed in Tables (under name variant 2).

To calculate double differential cross sections of concurre reactions for photons and electrons interacting with deuterium a aluminum (only for θ_p^{cm} = 90^o) nuclei , we have used codes of Lightbo and O'Conelli [14]. There is no the calculation of proton and pi yields from target's wall for other angles, because it is sma (5-10%). The number of equivalent photons has been calculated for t disoriented diamond target 6 mm thick.

Table II gives the results of calculating the proton chann counting rates resulting from the interaction of bremsstrahlu (d(γ,p)n, amorp.) and coherent photon beams (d(γ,p)n, crystal) wi the deuterium target, as well as proton and pion yields from photo and electrons beams together with the total counting rates (total π , total p). Proton counting rates with the mixed e+γ beam incident the oriented (total p, crystal) and disoriented (total p, amorp crystal is mainly due to the deuteron target, with the contributi from the electron component of the beam predominant. One sees from t last three columns that the proton channel counting rates does n exceed 3x10^3 sec^{-1} for angles θ_p^{cm} ≥ 60^o. Under these conditions t detector system will provide rejection of pions as well as positro and other particles. For θ_p^{cm} = 30^o the expected counting rate a considerably larger. Probably big counting rates does not allow to u electron currents more then about 5 μkA. The expected counting rate proton (total p, crystal) is about ≃ 10^{4}sec^{-1} for θ_p^{cm} = 30^o and f other angles does not exceed 3000 sec^{-1}.

The neutron counter counting rate cause by as neutron as a char particles. It has been estimated by integrating proton, pion a neutron spectra calculated according to the code [15] over t momentum range 50–1700 MeV/c accounting for particle absorption in t lead absorber and for neutron detecting efficiency. The energy of t primary electron beam is 4 GeV.

The counting rates of each of 12 counters of the neutr hodoscope by charged (π,p) particles and neutrons from photons a electrons are given in Table III. The contribution from the targ walls is insignificant and has not been accounted for. The tot counting rates (total p, π, n) of the neutron block is, mainly, due π-mesons. The neutron counting rate (total, n) is order of magnitu less. Thus, the counting rates of every neutron counter will n exceed ~ $10^6 sec^{-1}$. For the conventional electronics speed $\leq$ 10^{-8} s in a separate block one will provide effective rejection of charg particles.

Estimates based on the experimental data at Bates was t neutron flux 2.2×10^3 n/s μkA msr gr cm^{-2} at the angle 56.6^o for t electron energies 762 MeV from the deuterium target, and with t account of absorption in lead and counter efficiency give counti rates $\approx 2\times10^2$ which agrees with d(e,n)X estimates of Table III to t order of magnitude.

COUNTING RATE OF PROTON–NEUTRON COINCIDENCES

The counting rate of np coincidences has been calculated for t deuteron target under the assumption of full matching of solid angl of proton and neutron arms. One has accounted for neutron absorpti by the lead absorber shield and the efficiency. There have be calculated yields at real photons from the disoriented (d(γ, p) amorp) and oriented (d(γ, p)n, crystal) crystal as well as at virtu photons (d(e, p)n). Table IV gives the calculation results.

It is seen that for the oriented crystal the ratio of the d(p)n reaction yields to the d(e,p)n yield on the e^- beam considerably bigger than the corresponding ratio for the disorient crystal. The number of accidental coincidences has been estimat accounting for proton (total p, crystal) and neutron (total n) loa of one block under the assumption that the resolution time f coincidences is ~ 2×10^{-9} sec. The ratio of accidental and tr coincidences for all 12 blocks approaches 40% at high energies f angles $\theta_p^{cm} \geq 60^\circ$, Table V. At angle $\theta_p^{cm} = 30^\circ$ (for variant 1) th ratio may be some greater.

STATISTICS AND BEAM TIME

If one neglects the contribution from background coincidences f the empty target, then in our scheme of experiment one needs t measure the number of pn coincidences:

- with the mixed γ+e beam when the polarization vector i parallel $C_\parallel$ and perpendicular $C_\perp$ to the reaction plane as well as fo the disoriented crystal C_a;
- with the electron beam C_e (without the photon target).

The asymmetry value will be determined by the expression:

$$\Sigma = \frac{1}{P_\gamma} \frac{C_\parallel - C_\perp}{C_\parallel + C_\perp - 2C_e} \qquad (4$$

and the polarization P_γ value according to (3) from data on $C_\parallel - C_e$ $C_\parallel - C_e$ and $C_a - C_e$. The necessary statistics for values of $C_\parallel + C_\perp$ C_a and C_e providing the measurement accuracy $\Delta\Sigma_\gamma = \pm 0.05$ and pur beam time are listed in Table V. Starting from these values an corresponding counting rates of coincidences given in Table IV (tota np, crystal), (total np) and d(e, p)n the pure beam time is estimate for every energy and angle. Data are given in Table V.

In estimates we have used the calculated photon polarizatio values P_γ. Σ values at energies < 1 GeV and $\theta_p^{cm} = 90^\circ$ have been take from [12] and at larger energies they have been fixed arbitrarily value $\Sigma = 0.15$. Σ-values for other angles have been fixed at the sa value too. It should be say, that C values depend weakly on Σ values

At angle 30^{o} measurements would reasonable to limit by ran 0.6-1.6 GeV, if cross sections in this angle the same as at 9 (variant 1). If he theoretical calculation [13] true, then measuremen my be carry out up to 2 GeV (variant 2). The pure beam time f measurements at all five angles would amount $\simeq$ 87 hours (variant 1) $\simeq$ 76 hours (variant 2). The estimates given will be corrected in t process of detailed simulation of the experiment and of accumulati the experience of working with all the apparatus complex.

It is necessary to have additional beam time for :

- tests, apparatus calibration ~ 50 hours;
- changing the coherent peak energy, the angle, the magnet field ~ 80 hours;
- measurements with the empty target, ~ 50 hours;
- control of results reproduction, ~ 40 hours.

Thus the total beam time for the experiment proposed is estimated 300 hours.

EXPERIMENTAL VERIFICATION

Experimental verification of the measurement Σ-asymmetry on mix $\gamma+e^{-}$ beam in one arm was carried out in Kharkov Linac. Tl experimental layout was the same as is shown on fig.4. We used diamo single crystal with 1.8 mm thickness, which was orientated experimental hall on mixed $\gamma+e^{-}$ beam using the method supposed f hall "A" fig 6 and performed in Kharkov. It was described above.

The conditions of the experiment:

- electron beam energy 1.7 Gev;
- angle of proton detection $\theta_{p}^{cm} = 90^{o}$;
- energy of coherent photon peak 300 MeV;

– target with two appendix by 40 mm in diameter and 200 mm l
One of them was filled liquid deuterium,other liquid hydrogen.

The protons from the reaction (1) were detected by magn
spectrometer and telescope of scintillation counters.

The spectra of intensity the γ-radiation and its polarization
our experimental conditions were calculated and shown on fig.6.

Orientation dependencies of proton yields from deut
photodisintegration after electrodisintegration background subtrac
are shown on fig 7 for two cases: when vector polarization the ph
beam is parallel and perpendicular to reaction plane. The backgr
of the deuteron electrodisintegration was ≈ 80–85%, that practic
agree with calculation. The effective polarization calculated
expression (3) was about 63%. Here can see that yield of the reac
depend from direction of polarization vector of the beam. The valu
the asymmetry obtained from our measurements agree with experime
data [4],fig.1b.

RADIATION DAMAGE OF THE CRYSTAL

The working experience at the KhIPT Linac has shown the a
irradiating diamond monocrystal with the ~ 10^{20} electron/cm^2 dose
crystal qualities may deteriorate up to its destruction. We may
to perform all measurements with one or two monocrystals. Cry
orientation, testing measurements, apparatus tuning should be done
the lower electron intensities.

COLLABORATION CONDITIONS

The experiment proposed should be considered as a part of experime
program on studying the $\gamma d \rightarrow pn$ process proposed to be performed in
"A" [1]. And it may be performed simultaneously, e.g. with

experiment on proton polarization measurements using a part of th CEBAF experimental apparatus, i.e. spectrometer proton countir system, deuteron target, neutron detector.

The KhIPT will provide the device to obtain polarized photon. I also performs the preliminary orientation of diamond crystals at it Linac. This technique of asymmetry measurements with the mixed beam c electrons and photons at Kharkov will test in the energy range up t 0.8 GeV at angles $\theta_p^{cm} \geq 90^o$.

CONCLUSIONS

In conclusion one should note the following. First, the apparatu made for this proposal, allows one to measure the polarizatic parameters in reactions of photodisintegration of lightest nuclei: fc example, cross-section asymmetries of reactions, as well as th polarization observable in double polarization experiments (polarize beam-proton polarization) for d, ^{3}He and ^{4}He nuclei.

Second, the location of the photon target at such a smal distance (0.8-1 m) from the deuteron target is due, mainly, to th requirement not to disturb the hall "A" setting according to th project. It will be more advantageous, from the viewpoint of thi experiment, to increase this distance up to 10-15 m and to install sweeping magnet with beam damp. The beam size will increase by 3- mm, which is not critical, and one may perform the experiment withou photon beam collimation i.e. without intensity losses. Such a experimental scheme would allow to get rid of measurements with th removed photon target, would decrease the beam time by a factor nc less than 2, and would increase the accuracy of measurements. It woul reduce also the requirements to the cooling power of the deuterc target and the background.

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Table 1. Kinematic conditions of measurements.

$\vartheta_p^{cm} = 30^o$

E_γ GeV	ϑ_p^{Lab} deg	P_p GeV/c	T_p GeV
0.6	21.1	1.038	0.461
0.8	20.1	1.261	0.634
1.0	19.1	1.475	0.810
1.2	18.4	1.682	0.988
1.4	17.7	1.885	1.168
1.6	17.1	2.086	1.349
1.8	16.5	2.284	1.531
2.0	16.0	2.480	1.713

$\vartheta_p^{cm} = 60^o$

E_γ GeV	ϑ_p^{Lab} deg	P_p GeV/c	T_p GeV
0.6	43.4	0.944	0.392
0.8	41.3	1.135	0.534
1.0	39.5	1.317	0.678
1.2	38.0	1.491	0.824
1.4	36.6	1.661	0.970
1.6	35.4	1.828	1.116
1.8	34.4	1.992	1.264
2.0	33.4	2.154	1.411

$\vartheta_p^{cm} = 90^o$

E_γ GeV	ϑ_p^{Lab}	P_p GeV/c	T_p GeV	$(d\sigma/d\Omega)_D^{Lab}$ nb/sr
0.6	68.2	0.806	0.299	247
0.8	65.2	0.953	0.399	98
1.0	62.7	1.089	0.499	41
1.2	60.5	1.218	0.599	18
1.4	58.6	1.342	0.699	8.3
1.6	56.8	1.462	0.799	4.1
1.8	55.3	1.580	0.899	2.4
2.0	53.9	1.695	0.999	1.0

Table 1 (continue).

$\vartheta_p^{cm} = 120^{\circ}$

E_{γ} GeV	ϑ_p^{Lab} deg	P_p Gev/c	T_p GeV
0.6	97.6	0.654	0.206
0.8	94.1	0.751	0.264
1.0	91.1	0.838	0.320
1.2	88.5	0.918	0.374
1.4	86.2	0.994	0.428
1.6	84.1	1.066	0.482
1.8	82.1	1.135	0.534
2.0	80.4	1.202	0.587

$\vartheta_p^{cm} = 150^{\circ}$

E_{γ} GeV	ϑ_p^{Lab} deg	P_p GeV/c	T G[illegible]
0.6	134.5	0.525	0.1[illegible]
0.8	131.7	0.579	0.1[illegible]
1.0	129.1	0.624	0.1[illegible]
1.2	126.8	0.662	0.2[illegible]
1.4	124.7	0.697	0.2[illegible]
1.6	122.8	0.728	0.2[illegible]
1.8	121.0	0.757	0.2[illegible]
2.0	119.3	0.785	0.2[illegible]

Table II. Counting rates in the proton arm.

(targets wall)

E_γ GeV	I_e μka	Al$(\gamma,p)X$ sec^{-1}	Al$(e,p)X$ sec^{-1}	Al$(\gamma,\pi)X$ sec^{-1}	Al$(e,\pi)X$ sec^{-1}
			$\theta_p^{cm} = 90^o$		
0.6	1	1.60	7.6	1.26	3.38
0.8	1	0.49	3.4	0.33	0.92
1.0	5	1.03	9.1	0.38	1.04
1.2	10	0.88	9.9	0.07	0.18
1.4	30	1.22	16.5	–	–
1.6	30	0.62	9.4	–	–
1.8	50	0.58	9.2	–	–
2.0	50	0.40	5.7	–	–

(deuteron)

E_γ Gev	I_e μkA	$d(\gamma,p)n$ amorp sec^{-1}	$d(\gamma,p)n$ crystal sec^{-1}	$d(\gamma,p)X$ amorp sec^{-1}	$d(e,p)X$ sec^{-1}	$d(\gamma,\pi)X$ amorp sec^{-1}	$d(e,\pi)X$ sec^{-1}	total π+p amorp sec^{-1}	total p amorp sec^{-1}
					$\theta_p^{cm} = 90^o$				
0.6	1	25.6	79.9	–	129.6	80.1	207.0	456	164
0.8	1	9.7	28.6	–	70.2	21.2	56.7	163	84
1.0	5	19.4	53.1	–	195.8	24.3	63.0	314	225
1.2	10	16.3	40.8	–	305.6	4.8	11.7	349	333
1.4	30	21.5	46.7	–	430.6	–	–	470	470
1.6	30	10.6	22.3	–	128.2	–	–	149	149
1.8	50	10.3	20.2	–	108.0	–	–	128	128
2.0	50	4.2	8.1	–	65.5	–	–	76	76

Table II (continue).

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(γ,p)X amorp	d(e,p)X	d(γ,π)X amorp	d(e,π)X	total π+p amorp	total p amorp	tot p cry
Gev	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec

$\theta_p^{cm} = 30^o$ (variant 1)

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(γ,p)X amorp	d(e,p)X	d(γ,π)X amorp	d(e,π)X	total π+p amorp	total p amorp	tot p cry
0.6	1	19.5	61.2	5778	3987	11520	7731	29016	9765	126
0.8	1	7.20	21.2	4590	3033	8114	5139	20876	7623	98
1.0	1	2.80	7.64	3538	2236	5867	3512	15153	5774	74
1.2	2	2.29	5.72	5224	3220	8161	4685	21290	8444	104
1.4	4	1.97	4.28	7645	4640	11470	6300	30055	12275	144
1.6	2	0.48	1.01	2759	1681	3942	2099	10481	4440	47
1.8	1	0.14	0.27	995	623	1367	698	3683	1618	17
2.0	1	0.05	0.11	703	471	903	448	2525	1174	12

$\theta_p^{cm}=30^o$ (variant 2)

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(γ,p)X amorp	d(e,p)X	d(γ,π)X amorp	d(e,π)X	total π+p amorp	total p amorp	tot p cry
0.6	1	19.5	61.2	5778	3987	11520	7731	29016	9765	126
0.8	1	7.20	21.2	4590	3033	8114	5139	20876	7623	98
1.0	1	6.51	17.8	3538	2236	5867	3512	15153	5774	74
1.2	2	7.56	18.9	5224	1610	8161	4685	21290	8444	104
1.4	4	8.57	18.6	7645	4640	11470	6300	30055	12275	144
1.6	5	6.44	13.6	6898	4203	9855	5247	26203	11101	11
1.8	5	4.32	8.64	4977	3114	6926	3488	18505	8091	85
2.0	4	1.62	3.24	2812	1883	3611	1793	10099	4695	4

Table II (continue).

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(γ,p)X amorp	d(e,p)X	d(γ,π)X amorp	d(e,π)X	total π+p amorp	total p amorp	tot… p crys…
Gev	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec…
					$\vartheta_p^{cm} = 60^o$					
0.6	1	21.6	67.5	1130	1209	950	1110	4399	2339	288
0.8	1	8.04	23.8	674	695	368	414	2151	1369	169
1.0	3	9.45	25.9	1160	1193	540	586	3479	2353	291
1.2	5	6.52	16.3	1066	1166	439	461	3132	2232	263
1.4	10	5.65	12.3	1170	1431	441	517	3559	2601	289
1.6	10	2.76	5.80	610	803	210	202	1825	1413	147
1.8	30	4.75	9.36	869	999	268	245	2381	1868	194
2.0	30	1.94	3.62	399	486	98	81	1064	885	91
					$\vartheta_p^{cm} = 120^o$					
0.6	1	32.3	101.0	-	112	4.3	174	322.6	144.3	213.
0.8	1	12.8	37.6	-	64	-	-	76.8	76.8	101.
1.0	2	10.5	28.6	-	93	-	-	103.5	103.5	121.
1.2	5	11.3	28.2	-	189	-	-	200.3	200.3	217.
1.4	20	20.2	44.1	-	428	-	-	448.2	448.2	472.
1.6	30	15.0	32.0	-	381	-	-	396.0	396.0	413.
1.8	30	9.00	17.7	-	294	-	-	303.0	303.0	311.
2.0	50	6.26	11.7	-	311	-	-	317.3	317.3	322.

Table II (continue).

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(γ,p)X amorp	d(e,p)X	d(γ,π)X amorp	d(e,π)X	total π+p amorp	total p amorp	tota p crys
Gev	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec
					$\theta_p^{cm} = 150^o$					
0.6	1	42.3	132.2	-	92	-	-	-	134.3	224
0.8	1	17.6	51.9	-	56	-	-	-	73.6	107
1.0	2	15.2	41.5	-	85	-	-	-	100.2	126
1.2	5	17.0	42.5	-	170	-	-	-	187.0	212
1.4	10	15.8	34.5	-	285	-	-	-	300.8	319
1.6	20	16.5	34.5	-	494	-	-	-	510.5	528
1.8	30	14.9	29.5	-	661	-	-	-	675.9	690
2.0	30	6.40	12.0	-	606	-	-	-	612.4	618

Table III. Counting rates for one counter in the neutron arm.

θ^{cm}	θ_p^{Lab}	I_e	d(γ,p)X	d(e,p)X	d(γ,π)X	d(e,π)X	d(γ,n)X	d(e,n)X	total p,π,n	tot n
deg	deg	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec
30	133.5	1	-	2.81	797	138	54	261	1253	31
60	98.2	1	0.22	8.78	750	1462	88	294	2603	38
90	68.2	1	12.6	87	1917	3540	159	333	6049	49
90	53.9	1	235	512	4514	5008	283	482	11034	76
120	44.9	1	814	916	8972	10480	374	572	22128	94
150	21.2	1	5948	4109	37956	46062	1320	1170	96565	249

Table IV. Coounting rates for pn coincidences.

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(e,p)n	total pn amorp trues	total pn crystal trues	ratio amorp $\frac{d(\gamma,p)n}{d(e,p)n}$	ratio crystal $\frac{d(\gamma,p)n}{d(e,p)n}$	acci 10^{-}
GeV	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}			sec

$\theta_p^{cm} = 30^o$ (variant 1).

0.6	1	2.24	7.00	5.01	7.25	12.01	0.45	1.40	1.59
0.8	1	0.83	2.43	1.84	2.67	4.27	0.45	1.32	1.23
1.0	1	0.32	0.87	0.74	1.06	1.61	0.44	1.18	0.94
1.2	2	0.26	0.66	0.59	0.85	1.25	0.44	1.12	2.62
1.4	4	0.22	0.49	0.52	0.74	1.01	0.43	0.94	7.26
1.6	2	0.055	0.115	0.128	0.183	0.24	0.43	0.90	1.19
1.8	1	0.015	0.031	0.035	0.050	0.071	0.43	0.89	0.21
2.0	1	0.006	0.012	0.014	0.020	0.026	0.43	0.86	0.15

$\theta_p^{cm} = 30^o$ (variant 2).

0.6	1	2.24	7.00	5.01	7.25	12.01	0.45	1.40	1.59
0.8	1	0.83	2.43	1.84	2.67	4.27	0.45	1.32	1.23
1.0	1	0.75	2.02	1.71	2.46	3.73	0.44	1.18	0.94
1.2	2	0.86	2.21	1.97	2.83	4.18	0.44	1.12	2.62
1.4	4	0.98	2.13	2.27	3.21	4.40	0.43	0.94	7.26
1.6	5	0.74	1.55	1.72	2.46	3.27	0.43	0.90	7.43
1.8	5	0.49	1.02	1.15	1.65	2.17	0.43	0.89	5.26
2.0	4	0.19	0.37	0.43	0.62	0.80	0.43	0.86	2.44

Table IV (continue).

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(e,p)n	total pn amorp trues	total pn crystal trues	ratio amorp $\frac{d(\gamma,p)n}{d(e,p)n}$	ratio crystal $\frac{d(\gamma,p)n}{d(e,p)n}$	accid 10^{-2}
GeV	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}			sec^{-}
				$\theta_p^{cm} = 60^\circ$					
0.6	1	2.48	7.72	6.10	8.58	13.82	0.41	1.27	0.441
0.8	1	0.92	2.71	2.31	3.23	5.02	0.40	1.17	0.259
1.0	3	1.09	2.96	2.75	3.84	5.71	0.40	1.08	1.336
1.2	5	0.75	1.86	1.91	2.66	3.77	0.39	0.97	2.017
1.4	10	0.65	1.41	1.67	2.32	3.08	0.39	0.84	4.429
1.6	10	0.32	0.67	0.83	1.15	1.50	0.39	0.73	2.255
1.8	30	0.54	1.07	1.43	1.97	2.50	0.38	0.75	8.920
2.0	30	0.22	0.41	0.68	0.90	1.09	0.32	0.60	3.694
				$\theta_p^{cm} = 90^\circ$					
0.6	1	2.93	9.14	7.08	10.01	16.22	0.41	1.29	0.042
0.8	1	1.12	3.28	2.90	4.02	6.18	0.39	1.13	0.021
1.0	5	2.22	6.08	6.23	8.45	12.31	0.36	0.98	0.292
1.2	10	1.86	4.66	5.51	7.37	10.17	0.34	0.85	0.857
1.4	30	2.46	5.34	7.72	10.18	13.06	0.32	0.69	3.836
1.6	30	1.22	2.55	4.12	5.34	6.67	0.30	0.62	1.300
1.8	50	1.17	2.32	4.07	5.24	6.39	0.29	0.57	1.967
2.0	50	0.49	0.93	1.72	2.21	2.65	0.28	0.54	1.283

Table IV (continue).

E_γ	I_e	d(γ,p)n amorp	d(γ,p)n crystal	d(e,p)n	total pn amorp trues	total pn crystal trues	ratio amorp $\frac{d(\gamma,p)n}{d(e,p)n}$	ratio crystal $\frac{d(\gamma,p)n}{d(e,p)n}$	acci 10^{-2}
GeV	μkA	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}	sec^{-1}			sec
				$\theta_p^{cm} = 120^o$					
0.6	1	3.70	11.55	11.83	15.53	23.38	0.31	0.98	0.081
0.8	1	1.46	4.30	4.86	6.32	9.16	0.30	0.88	0.038
1.0	2	1.20	3.28	4.22	5.42	7.50	0.28	0.78	0.092
1.2	5	1.30	3.22	5.00	6.30	8.22	0.26	0.64	0.410
1.4	20	2.31	5.05	10.39	12.70	15.44	0.22	0.49	3.572
1.6	30	1.75	3.67	7.70	9.45	11.37	0.23	0.48	4.680
1.8	30	1.03	2.03	5.05	6.08	7.08	0.20	0.40	3.538
2.0	50	0.72	1.31	3.40	4.12	4.71	0.21	0.40	6.107
				$\theta_p^{cm} = 150^o$					
0.6	1	4.84	14.68	19.64	24.48	34.32	0.25	0.75	0.223
0.8	1	2.02	5.94	8.68	10.70	14.62	0.23	0.68	0.107
1.0	2	1.74	4.74	8.12	9.86	12.86	0.21	0.58	0.262
1.2	5	1.94	4.86	9.73	11.67	14.59	0.20	0.50	1.059
1.4	10	1.81	3.95	12.58	14.39	16.53	0.15	0.31	3.185
1.6	20	1.88	3.96	10.69	12.57	14.65	0.18	0.37	10.53
1.8	30	1.71	3.38	10.26	11.97	13.64	0.17	0.33	20.62
2.0	30	0.73	1.37	4.59	5.32	5.96	0.16	0.30	18.46

Table V. Statistic and beam time.

E_γ GeV	I_e μkA	P_γ	Σ	$C_\parallel + C_\perp$ counts	C_a counts	C_e counts	$\frac{\text{accid}}{\text{trues}}$ %	T hours
				$\theta_p^{cm} = 30^\circ$ (variant 1)				
0.6	1	0.59	0.15	4510	642	941	1.59	0.18
0.8	1	0.56	0.15	5270	640	1138	3.45	0.58
1.0	1	0.53	0.15	6444	662	1473	7.01	1.84
1.2	2	0.50	0.15	7800	658	1861	25.2	2.82
1.4	4	0.47	0.15	10236	662	2632	86.3	4.47
1.6	2	0.45	0.15	11586	664	3026	59.5	21.0
1.8	1	0.40	0.15	15686	673	4228	37.6	98.7
2.0	1	0.35	0.15	21823	679	6029	67.6	362.2
							total	491.79
					0.6–1.6 GeV		total	30.89
				$\theta_p^{cm} = 30^\circ$ (variant 2)				
0.6	1	0.59	0.15	4510	642	941	0.79	0.18
0.8	1	0.56	0.15	5270	640	1138	1.73	0.58
1.0	1	0.53	0.15	6444	662	1473	3.02	0.79
1.2	2	0.50	0.15	7800	658	1861	7.59	0.85
1.4	4	0.47	0.15	10236	662	2632	19.9	1.03
1.6	5	0.45	0.15	11586	664	3026	27.4	1.55
1.8	5	0.40	0.15	15686	673	4228	29.6	3.14
2.0	4	0.35	0.15	21823	679	6029	37.5	11.78
							total	19.90

Table V (continue).

E_γ GeV	I_e μkA	P_γ	Σ	$C_\parallel + C_\perp$ counts	C_a counts	C_e counts	accid/trues %	T hours
				$\theta_p^{cm} = 60^o$				
0.6	1	0.59	0.15	4908	739	1084	0.38	0.17
0.8	1	0.56	0.15	5448	759	1254	0.62	0.39
1.0	3	0.53	0.15	7079	771	1706	2.81	0.57
1.2	5	0.50	0.15	8742	777	2212	6.42	0.97
1.4	10	0.47	0.15	11522	796	3124	14.1	1.65
1.6	10	0.45	0.15	13293	809	3684	18.0	3.89
1.8	30	0.40	0.15	18227	816	5240	43.1	3.16
2.0	30	0.35	0.15	30633	1041	9545	40.7	12.03
							total	22.83
				$\theta_p^{cm} = 90^o$				
0.6	1	0.59	0.15	4882	728	1070	0.031	0.15
0.8	1	0.56	0.23	6190	1944	1455	0.041	0.55
1.0	5	0.53	0.20	7964	1654	2021	0.283	0.32
1.2	10	0.50	0.15	10206	979	2758	1.040	0.45
1.4	30	0.47	0.15	14548	1100	4304	3.522	0.49
1.6	30	0.45	0.15	18222	1229	5624	2.335	1.20
1.8	50	0.40	0.15	25438	1285	8101	3.694	1.73
2.0	50	0.35	0.15	35570	1335	11549	5.810	5.76
							total	10.65

Table V (continue).

E_γ GeV	I_e μkA	P_γ	Σ	$C_\parallel + C_\perp$ counts	C_a counts	C_e counts	$\frac{\text{accid}}{\text{trues}}$ %	T hours
				$\theta_p^{cm} = 120^\circ$				
0.6	1	0.59	0.15	6278	1117	1590	0.041	0.13
0.8	1	0.56	0.15	7722	1191	2047	0.050	0.40
1.0	2	0.53	0.15	9943	1304	2799	0.147	0.62
1.2	5	0.50	0.15	13899	1530	4226	0.598	0.77
1.4	20	0.47	0.15	22566	1960	7597	2.778	0.65
1.6	30	0.45	0.15	25246	1901	8545	4.952	0.98
1.8	30	0.40	0.15	40534	2286	14465	6.005	2.49
2.0	50	0.35	0.15	54092	2139	19536	15.53	4.93
							total	10.97
				$\theta_p^{cm} = 150^\circ$				
0.6	1	0.59	0.15	8094	1647	2291	0.077	0.12
0.8	1	0.56	0.15	10288	1832	3056	0.088	0.34
1.0	2	0.53	0.15	13934	2104	4396	0.244	0.51
1.2	5	0.50	0.15	19195	2367	6400	0.871	0.60
1.4	10	0.47	0.15	40120	3988	15141	2.372	1.09
1.6	20	0.45	0.15	36100	2962	13171	8.625	1.09
1.8	30	0.40	0.15	54379	3251	20459	18.14	1.74
2.0	30	0.35	0.15	82154	3549	31598	36.98	5.93
							total	11.42

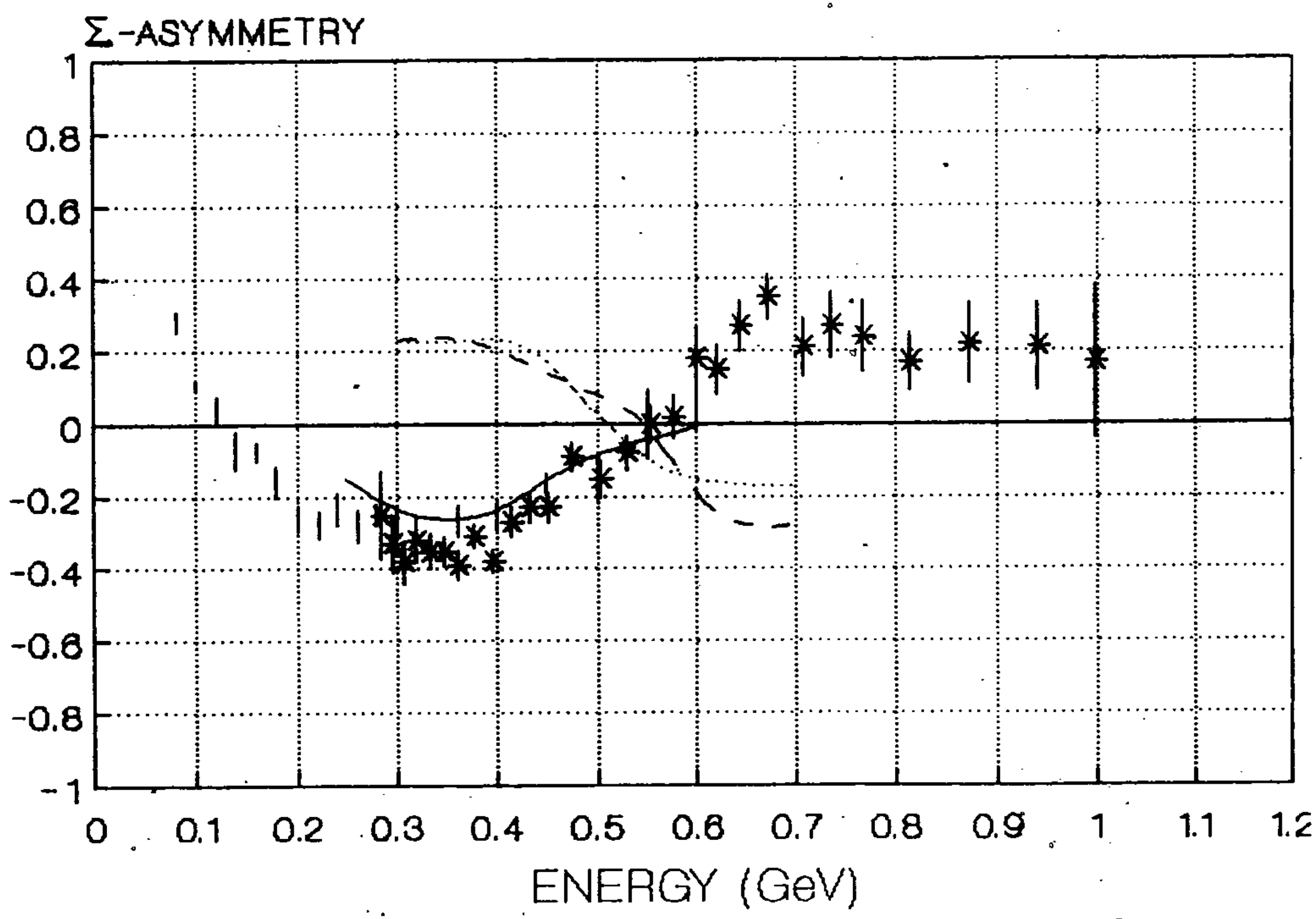

Fig.1a. Asymmetry of the cross section of the reaction $d(\gamma,p)n$ at $\Theta_p^{cm}=90^\circ$. Experimental data: | - from ref. [4]; ✱ - from ref. [12]. Theoretical curves: ——— - from ref. [10]; .... - from ref. [15]; – – – - from ref. [8] with two dibaryon resonances $1(3^-)$ and $0(3^-)$.

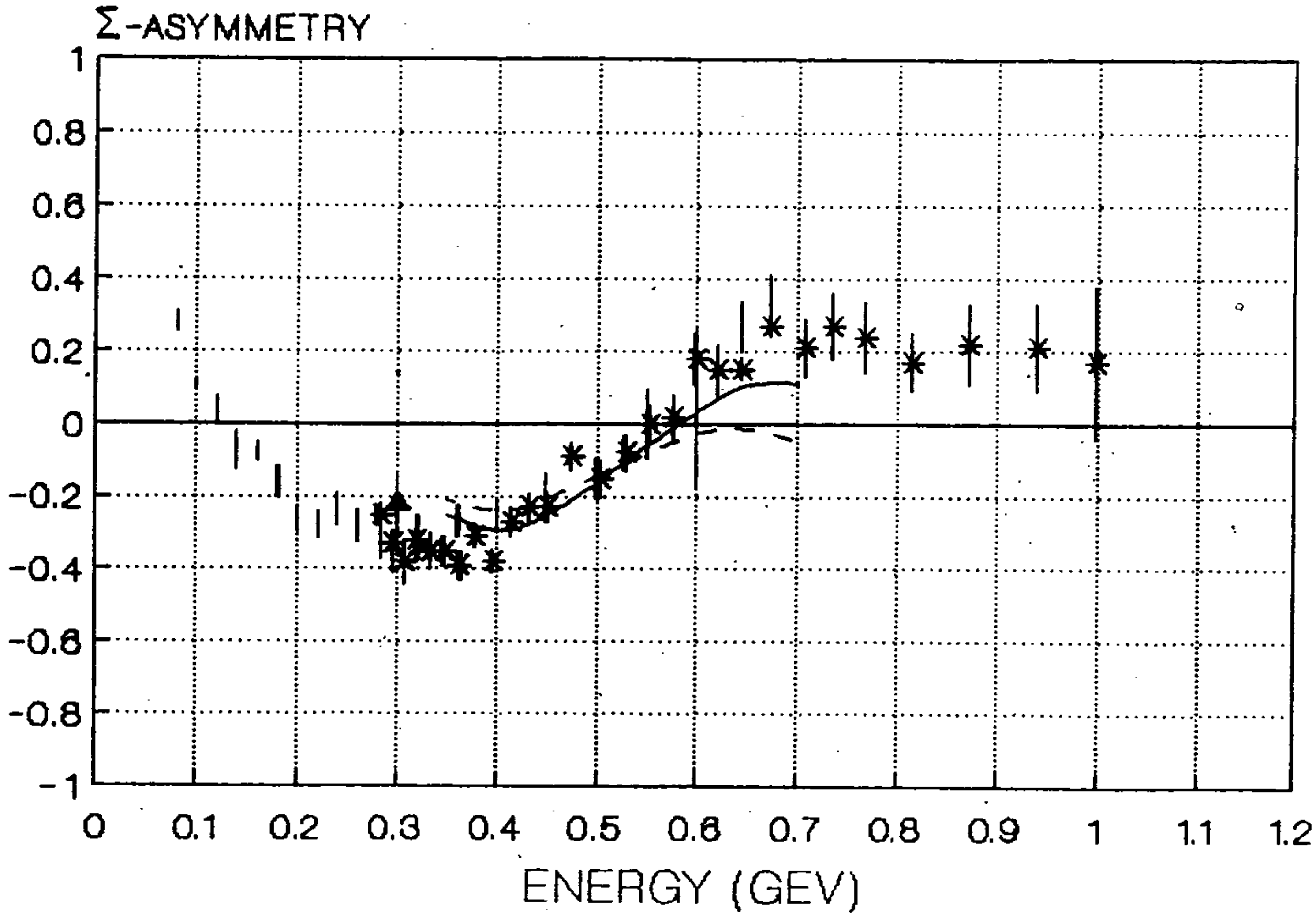

Fig.1b.The same as in fig.1a. Theoretical curves from ref.[9]:--- - without dibaryon resonances; ——— - with $1(2^+)$, $1(3^-)$ and $0(3^+)$ resonances. ▲ - our data,obtained on mixed γ+ e^- beam Kharkov, 1991.

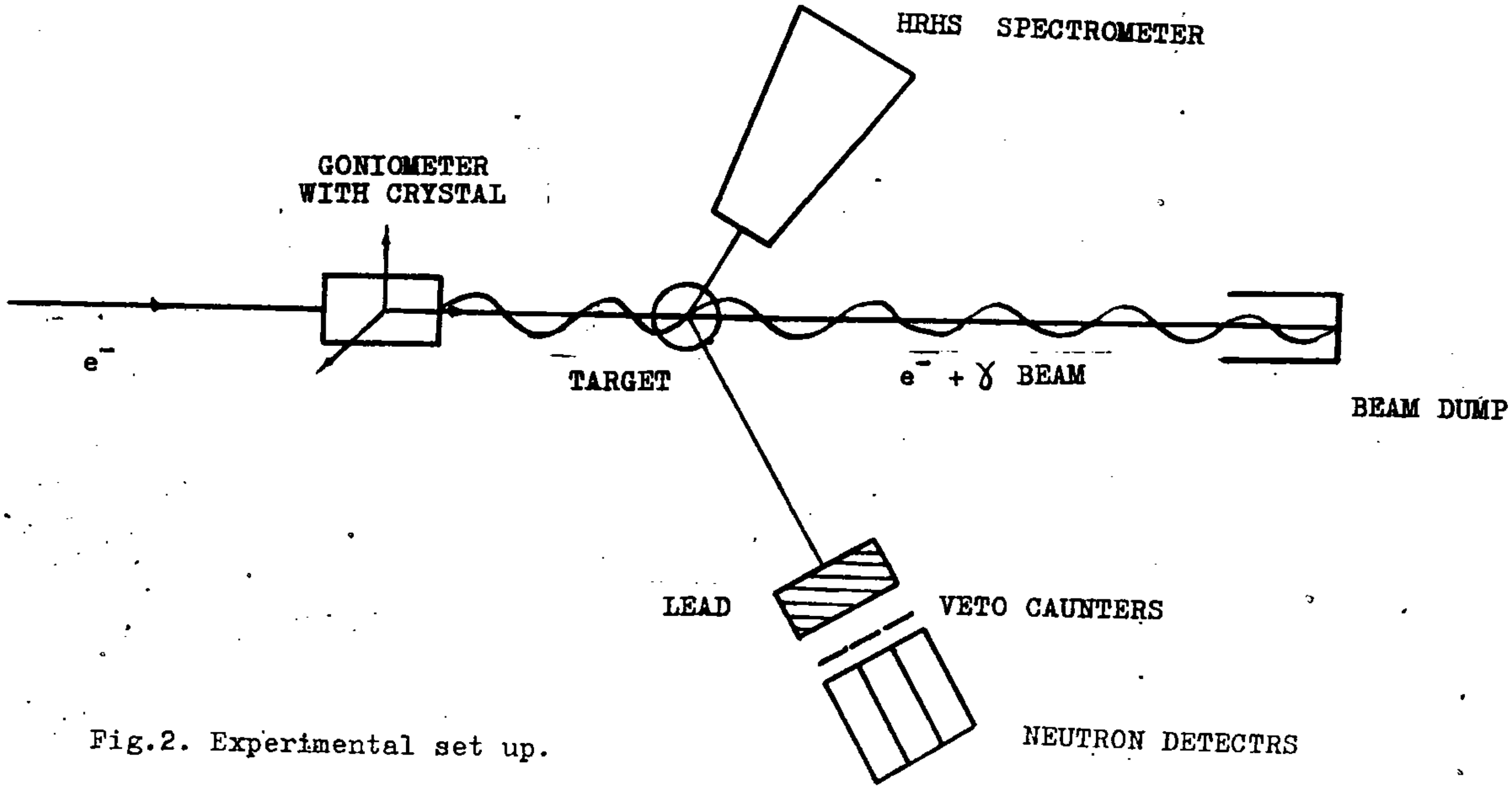

Fig.2. Experimental set up.

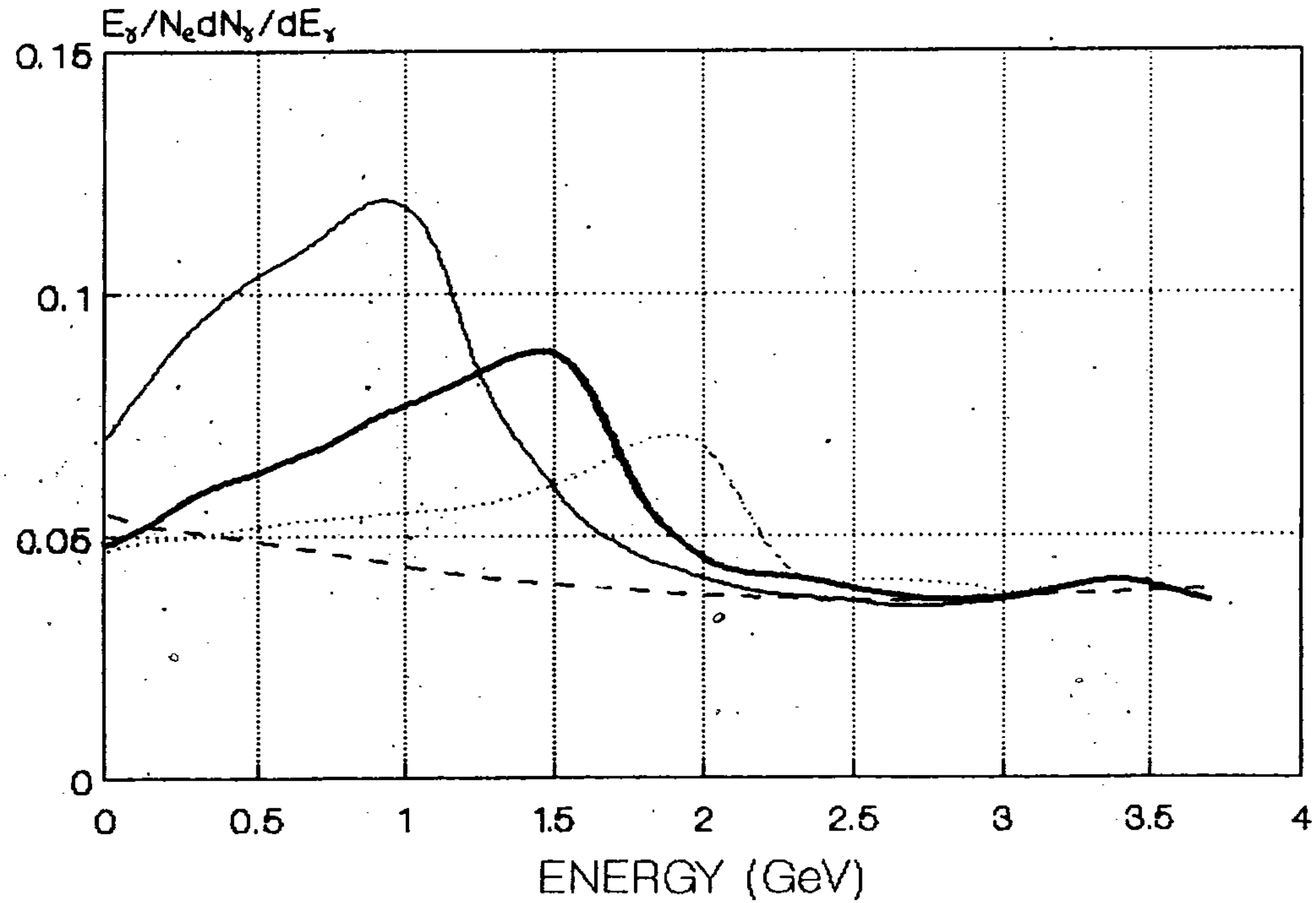

Fig.3a. Spectra of coherent bremsstrahlung for electron energy E_0 = 4 GeV and peak photon energies 1 GeV (———), 1.5 GeV (———), 2 GeV (·········). Diamond,orientation $(2,\bar{2},0)$, thick 6 mm.----- bremsstrahlung spectrum.

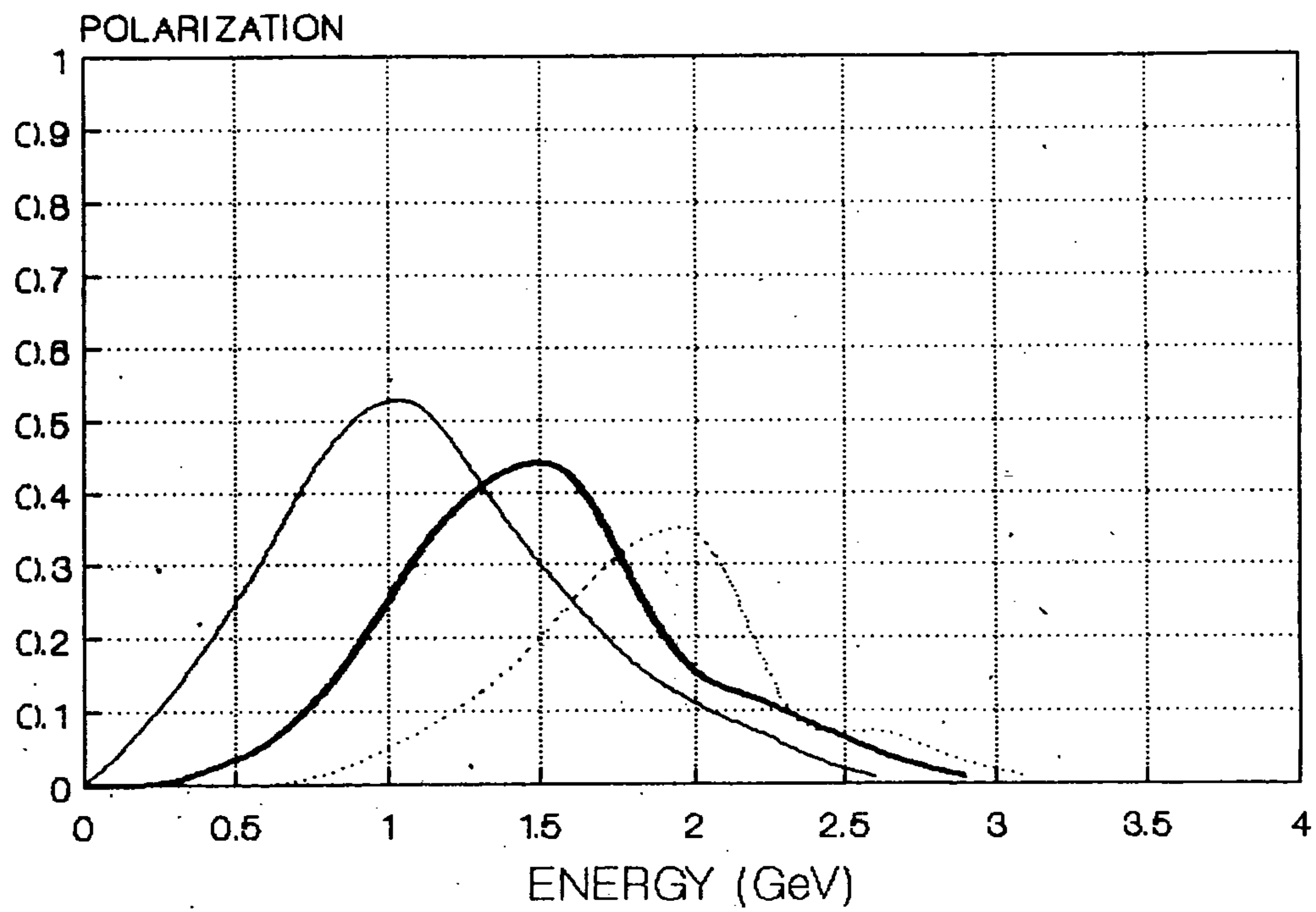

Fig.3b. Polarization of cocherent bremsstrahlung. Notation and conditions the same as in fig.3a.

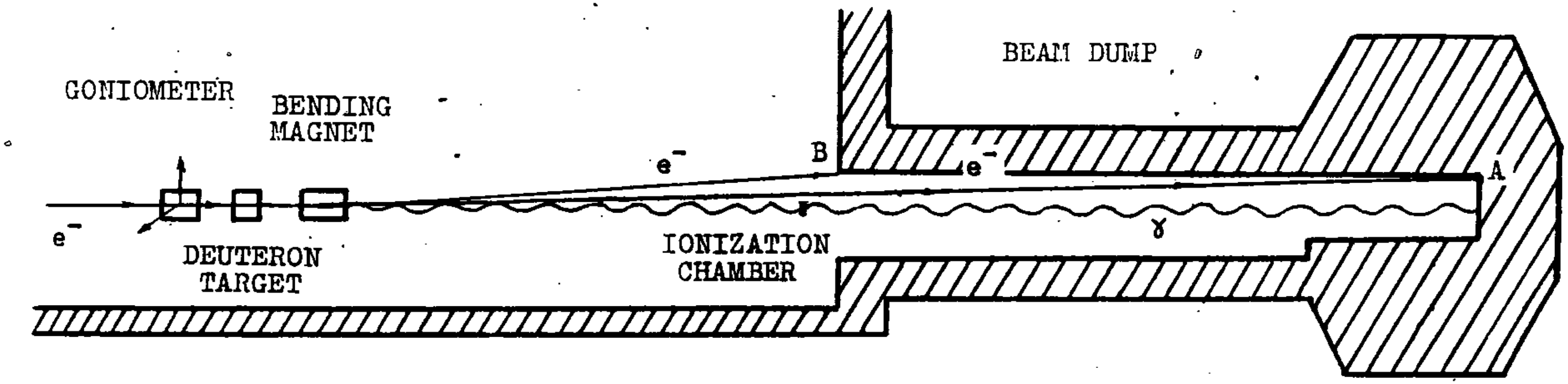

Fig.4. Experimental set up for crystal orientation.

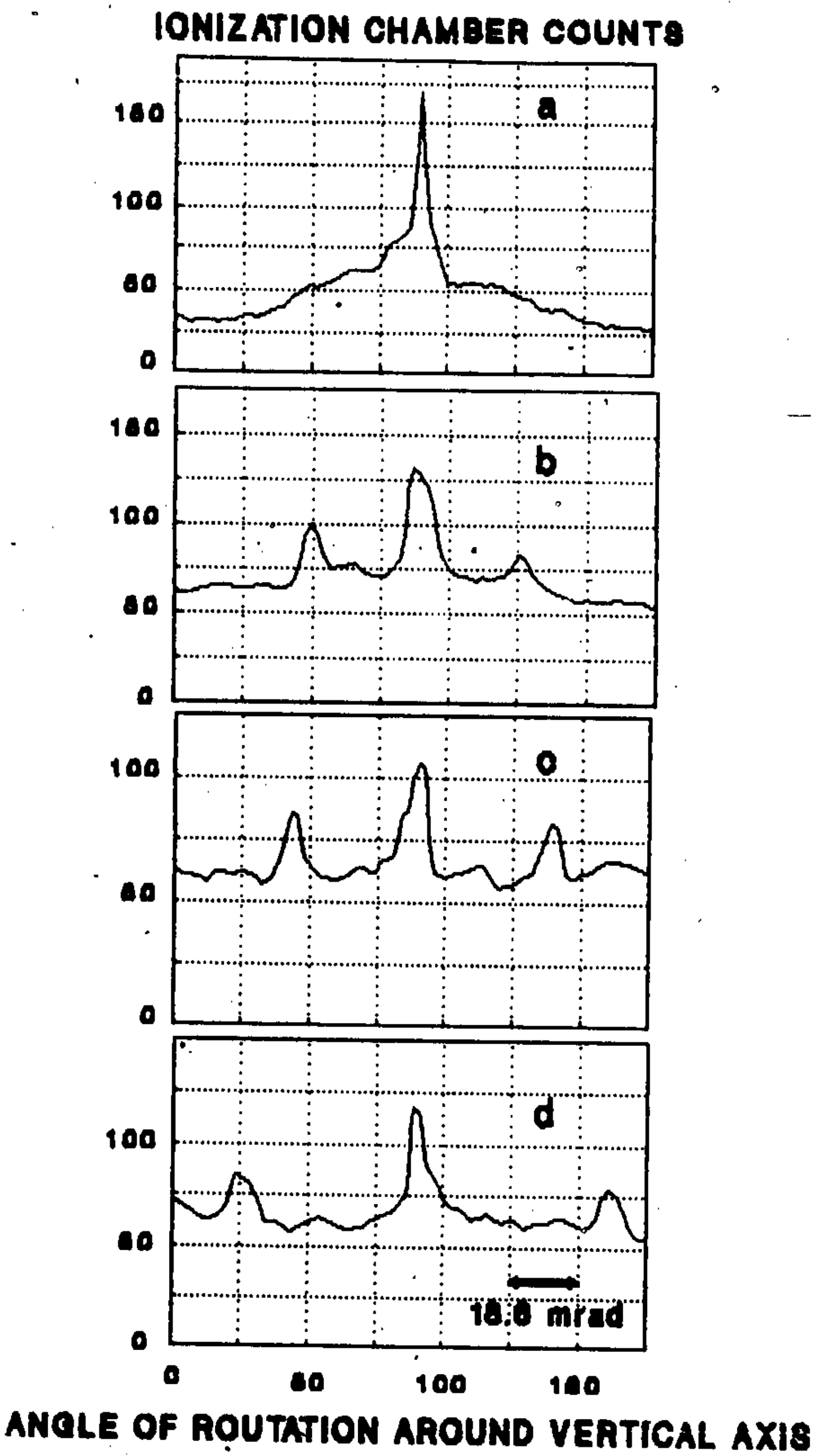

Fig.5. Orientation dependences of counts of ionization chamber when electron beam is deflected by bending magnet after passing through the crystal. E_0 = 1.2 GeV. a) ϕ = 0 (axial orientation) b) ϕ = 15.6 mrad; c) ϕ = 23.6 mrad; d) ϕ = 27.6 mrad.

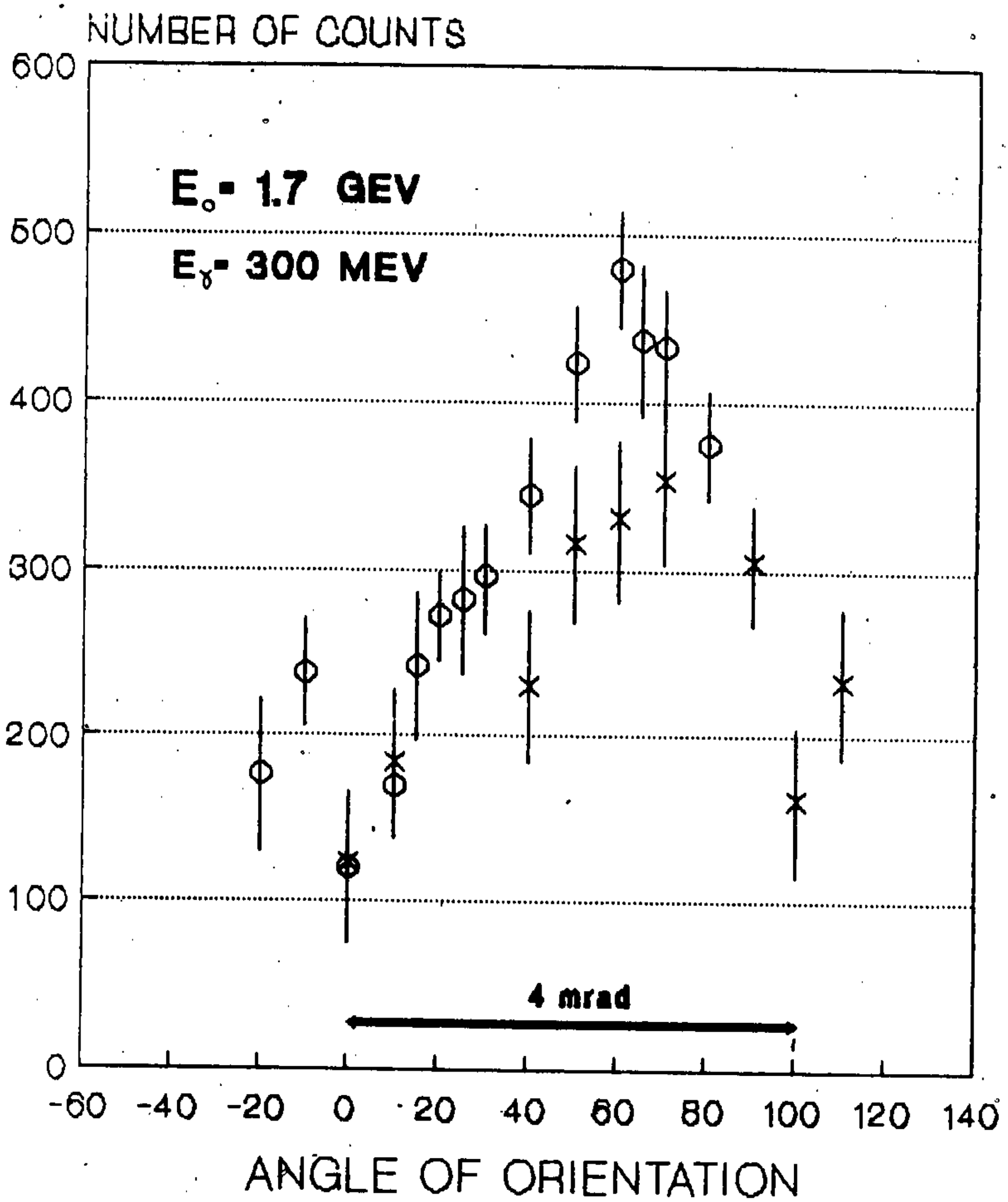

Fig.6. Orientation dependencies of proton yields from reaction photo-disintegration of the deuteron. ϕ (⁎) – polarization vector of the γ – beam perpendicular (parallel) to the reaction plane. $\theta_p^{cm} = 90°$.